

Review Paper: Balance in the Blind: A Systematic Review



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ABSTRACT

Purpose: This paper reviews the studies on balance in the blind.

Methods: The paper comprehensively reviewed studies on balance in the blind from the following databases: PubMed, MEDLINE, Web of Science, ScienceDirect, Cochrane Central Register of Controlled Clinical Trials, Google Scholar, and Scopus, from 2001 to 2019. Also, other available papers were examined.

Results: Out of 35 evaluated studies, 32 articles were fully represented and the rest were only summarized. These articles covered two issues: 1) balance adaptation in the blind, 2) the effects of training protocols on the balance in the blind.

Conclusion: The blind suffer from poor balance. However, they tend not to differ from normal people, when sufficient data from the vestibular and proprioception systems are available. Also, balance in the blind improves by age, which increases the efficiency and maturity of vestibular and proprioception systems. The blind tend to be more reliant on the hip than ankle strategy. All the training protocols reviewed in this paper have positively affected balance in the blind. Nevertheless, it was impossible to determine the most efficient protocol, and further qualitative studies are required for this purpose.

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Highlights

- A comprehensive review of the literature showed poor balance in the blind.
- Considering vestibular and proprioception inputs, the blind showed similar performance as that of sighted subjects.
- Balance in the blind improved by age because of the development of vestibular and proprioception systems.
- The blind mostly rely on the hip strategy.
- All training protocols and exercises were found to have positive effects on balance in the blind.

Plain Language Summary

It was found that the blind suffer from poor balance. However, they tend to be no different from normal people when sufficient data from vestibular and proprioception systems are available. It was also found that balance in the blind improves by age that increases the efficiency and maturity of vestibular and proprioception systems. The blind tend to be more reliant on hip than ankle strategy. All the training protocols reviewed in this paper have positively affected balance in the blind.

1. Introduction

The key nervous components of postural control include motor processes, such as neuromuscular synergies, and sensory processes, such as visual, vestibular, and proprioception systems [1, 2]. The vestibular receivers play a significant role in basic motion responses (maintaining head and posture) as they receive input related to the position of the head in space and generating reflexes [3]. Moreover, the somatosensory system provides information on the body's periphery and helps to realize the signals of pain, heat, touch, and proprioception. The visual system collects information about external body position [4]. Postural control occurs when the relationship between sensory input and appropriate motion responses, such as efficient muscular strength is established [5]. Besides, the poor performance of postural control occurs when one of these systems is impaired [6].

The visual system provides immediate information about the environment to the nervous system and plays an essential role in establishing balance [7]. Visual input acts as a significant sensory source for postural states [8]. Thus, any sort of visual impairment is directly related to movement dysfunction and balance instability and negatively affects static and dynamic balance [7]. Blind people received fewer motion pattern signals in the central nervous system and had lower balance performance, compared with normal people [9]. In this regard, exer-

cise improves and integrates postural control in the central nervous system [10]. The current paper seeks to answer the following questions: does training intervention improve balance in the blind? What are effective control mechanisms to improve balance in the blind? What are the most effective training protocols? In the absence of visual input, do other sensory systems help to maintain balance in the blind?

2. Materials and Methods

The present study comprehensively reviewed balance in the blind from databases, including Embase, ScienceDirect, PubMed, CINAHL, Google Scholar, MAGIRAN, IRANDOC, IranMedex, MedLib, and SID. It also covered a 19-year duration from 2001 to 2019 and used the combination of the following keywords: blindness/acquired blindness/congenital blindness × visual disorder/visually impaired person × postural control/balance. Also, the search was restricted to filters, such as English language, Persian language, human, original article, and review article. Initially, the title and summary of the resulting articles were carefully studied and those that did not meet the inclusion criteria were excluded from analysis. Inclusion criteria were study on blind population, articles in Persian or English, evaluation for balance in the blind, and the clear analysis of balance. Finally, a total number of 35 articles were obtained.

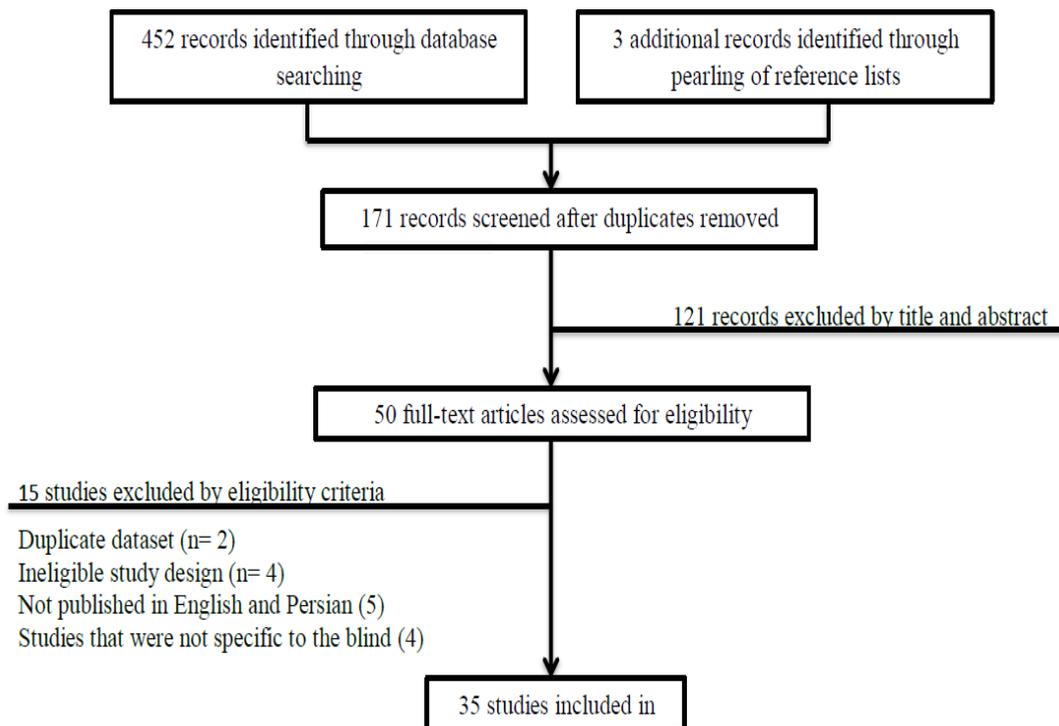


Figure 1. Flowchart for the screening of articles

3. Results

Figure 1 shows the selection process of the study. The search resulted in a total number of 452 articles. Moreover, three more articles were obtained from manual searching. However, the irrelevant articles were excluded, and overall, 171 abstracts were studied. Next, 121 articles were eliminated from the study, and only 50 candidate articles were chosen for full examination. Out of the candidate articles, only 35 were selected for final examination to check for: 1) balance adaptation in the blind (Table 1 and 2) the effects of training protocols on balance in the blind (Table 2).

Ray et al. studied the effects of visual impairment on postural control and the balance strategy in the blind and reported significant differences in balance scores for people in challenging situations. These authors also showed that the blind mostly rely on hip strategy [9]. Salari et al. studied balance recovery strategies, manipulating the somatosensory, visual, and vestibular systems in healthy and blind populations. The results indicated that the healthy population had a significantly different average hip and ankle sway and showed greater anterior-posterior as well as posterior-anterior perturbations. These authors also reported that the hip-to-ankle fluctuation rate (dominant strategy for balance recovery) significantly differed in all positions. Their results indicated that both groups

applied abrupt anterior-posterior and posterior-anterior perturbations for balance recovery, and then, showed different mechanisms and impulses. The blind used hip strategy for balance recovery but relied on somatosensory input as a superior balance system [11].

Nakata et al. examined automatic postural responses in subjects with congenital blindness and found that the electromyography activity of gastrocnemius muscle in the blind was lower than in their healthy counterparts. However, in response to the disorder, no delay was observed in the initiating electromyography activity of the lower extremity with closed or open eyes. Moreover, the blind showed greater agility than healthy participants to respond to the sensory-motor stimuli created by platform movement, but the two groups did not differ in upward or downward finger rotation. The same muscular activation delay and reflection time in the two groups indicate that congenital blindness does not affect spinal tensile reflex, however, it may affect the voluntary performance of the cortex. Also, the two groups did not significantly differ in the average fluctuation score of postural control with open or closed eyes, though the blind group showed greater fluctuation after backward transfer with open eyes. These results show that congenital blindness does not affect postural sway control in response to the disorder [12]. Horvat et al. studied isokinetic peak force and strength in visually impaired and blind adults. The

Table 1. Results of balance adaptation studies in the blind

Authors	PEDro Scale	Article Title	Sample Size	Age (y) Range	Measured Variables	Instrument
Ray et al. [9]	8	The impact of vision loss on postural stability and balance strategies in individuals with profound vision loss	Control group=23 Experimental group=25	Control group=38.2±14.42 Experimental group=39.8±14.38	Balance and balance recovery strategy	NeuroCom EquiTest System
Salari et al. [11]	4	Assessment of balance recovery strategies during manipulation of somatosensory, vision, and vestibular system in healthy and blind women	Control group=30 Experimental group=30	27 to 36	Balance recovery strategy	Biodex device and Y balance test
Nakata et al. [12]	7	Automatic postural response systems in individuals with congenital total blindness	Control group=9 Experimental group=9	Control group=19 to 24 Experimental group=19 to 24	Posture control	Force platform and EMG
Horvat et al. [13]	6	Comparison of isokinetic peak force and power in adults with partial and total blindness	Control group=12 Experimental group=12	Control group=35.1±13.4 Experimental group=36.2±13.2	Posture control	HUMAC-NORM isokinetic dynamometer
Ray et al. [14]	5	Clinical assessment of functional movement in adults with visual impairments	Visual impairment group=9 Blind group=9	20 to 58	Functional balance	Timed up-and-go and 30-second sit-to-stand
Giagazoglou et al. [15]	5	Static balance control and lower limb strength in blind and sighted women	Control group=10 Experimental group=10	Control group=33.5±8.3 Experimental group=33.5±7.9	Examining the isokinetic and isometric strength of the knee and ankle muscles and comparing the center of pressure	Force platforms and the CoP variations, Cybex dynamometer
Aydog et al. [16]	5	Dynamic postural stability in blind athletes	Sighted group=20 Goalball players group=20 Blind sedentary group=20	Sighted group=24.67±5.82 Goalball players group=24.9±4.29 Blind sedentary group=26.24±4.26	Posture control	Biodex Stability System
Tomomitsu et al. [17]	4	Static and dynamic postural control in low-vision and normal-vision adults	Control group=25 Experimental group=25	Control group=26.1±4 Experimental group=28.6±6	Static and dynamic balance	Functional tests
Müürsepp et al. [18]	7	Impact of visual impairment on static and dynamic postural control and habitual physical activity in children aged 10-16 years	Control group=13 Experimental group=13	10 to 16	Posture control	Platform Kistler
Häkkinen et al. [19]	8	Neuromuscular function and balance of prepubertal and pubertal blind and sighted boys	Blind group before puberty=8 Blind group after puberty=8	Blind group before puberty=9 to 13 Blind group after puberty=15 to 18	Muscle mass thickness, electromyography and maximal isometric strength, dynamic explosive actions, and balance	Isokinetic dynamometer, force platform, and EMG
Rutkowska et al. [20]	6	A comparison of body balance of blind children aged 7-16 years in sex and age categories	Blind children group=27 Blind teen group=33	Blind children group=6 to 11 Blind teen group=12 to 17	Body balance	Stabilographic platform
Barati et al. [21]	6	The growth status of balance capabilities of Visually impaired children, blind and their healthy counterparts	Visual impairment group=30 Blind group=16 Healthy group=65	8 to 12	Static and dynamic balance	Static balance=Romberg test Dynamic balance=balance board test
Rutkowska et al. [22]	8	Balance functional assessment in people with visual impairment	Blind children group=56 Blind teen group=71	Blind children group=6 to 11 Blind teen group=12 to 16	Functional balance	Bruininks-Oseretsky test
Melzer et al. [23]	9	The influence of an auditory-memory attention-demanding task on postural control in blind persons	Control group=9 Experimental group=9	Control group=46.9±12.9 Experimental group=47.8±12.9	Postural control	Force platform

Authors	PEDro Scale	Article Title	Sample Size	Age (y) Range	Measured Variables	Instrument
Ozdemir et al. [24]	8	Sensorimotor posture control in the blind: Superior ankle proprioceptive acuity does not compensate for vision loss	Control group=15 Experimental group=13	Control group=20 to 65 Experimental group=25 to 58	Postural control	Force platform
Schmid et al. [25]	7	Equilibrium during static and dynamic tasks in blind subjects: no evidence of cross-modal plasticity	Control group=25 Experimental group=25	Control group=36±13.5 Experimental group=43±5.9	Postural control	Force platform
Shomeil Shushtary et al. [26]	6	Vestibular-evoked myogenic potential in congenitally blind patients versus normal subjects	Control group=20 Experimental group=20	Control group=21.95±2.16 Experimental group=22.5±2.83	Vestibular-evoked myogenic potential	Tone burst stimulus
Farsi et al. [27]	5	Dual-task effects in sensory systems interference condition on blind and sighted persons balance	Control group=12 Experimental group=12	Control group=22.67±5.33 Experimental group=25.08±4.68	Postural control	Biodex Stability System
Mohammadi et al. [28]	6	Better functioning of the somatosensory system in postural control of blind athletes compared to non-athletes	Nonathlete vision group=10 Nonathlete blind group=10 Blind athlete group=10	Nonathlete vision group=18.20±1.47 Nonathlete blind group=18.70±1.13 Blind athlete group=19.20±1.13	Postural control	Biodex Stability System

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results showed that the subjects had better physical performance at low speed. Besides, gender differences were observed in both groups, but the groups did not significantly differ. Their results indicate that physical performance is similarly impaired in visually impaired and blind people [13]. Ray et al. performed a clinical analysis of the functional performance of visually impaired people and reported lower balance and strength indexes [14]. Furthermore, Giagazoglou et al. studied the isometric and isokinetic power of ankle and hip muscles in female and male blind and sighted subjects. They found that anterior-posterior and interior-exterior balance controls were better in sighted than in blind subjects. However, no significant difference was found between the study groups, in closed eye conditions. Considering the isometric and concentric power of the muscles of the lower extremity, it was asserted that the blind had a poor performance in balance tests [15].

Aydog et al. compared dynamic posture stability between blind athletes, normal people, and inactive blinds. They realized that the blind generally had poor balance, but blind athletes showed greater balance than inactive blinds [16]. Tomomitsu et al. studied static and dynamic balance in visually impaired and normal people and reported that visually impaired subjects had lower postural stability in dynamic tests and soft surfaces. Moreover, visual feedback was more important for them to determine balance [17]. Mürsepp et al. selected 13 normal and 13 visually impaired children to investigate the effects of visual disorder on postural control with open and closed eyes. They found no difference in postural control with

closed eyes, but normal children showed significantly greater postural control with open eyes [18].

Häkkinen et al. studied neuromuscular performance in blind subjects before and after puberty, as compared with normal people. These authors found no significant difference in the muscle mass volume, maximum muscular strength, and vertical jump. Moreover, the blind showed poorer single-foot balance, before puberty. Disregarding the vision, the blind and normal people do not differ from each other [19]. Rutkowska et al. examined the effects of gender and age on balance in the blind and reported no difference between male and female blind subjects and for the age groups of 7 to 11 years and 12 to 16 years [20]. Ahmadi Barati et al. studied the growth status of the balance capabilities of visually impaired and blind children and their healthy counterparts (age range, 8-12 years). The results showed a significant difference in balance capabilities between visually impaired and healthy children [21]. Also, Rutkowska et al. studied balance in visually impaired subjects, based on the Bruininks-Oseretsky test of motor proficiency second edition (BOT™-2). These researchers tried to figure out the highest balance disorder in terms of vision loss and the age of blindness. They used 127 subjects (66 visually impaired and 61 healthy), including 68 females and 59 males in the age range of 6 to 16 years. They used the Bruininks-Oseretsky test of motor proficiency to measure static balance and found that gender played no role in maintaining balance but the age and intensity of blindness significantly affected balance. Besides, the lowest level of balance was observed in the age group of 7 to 11 years. It is needed to develop physical fitness pro-

Table 2. Results of the study on the effect of training protocols on the balance of the blind

Authors	PEDro Scale	Article Title	Sample Size	Age (y) Range	Measured Variables	Instrument	Main Results
Jazi et al. [29]	4	Effect of selected balance exercises on the dynamic balance of children with visual impairments	Control group=9 Experimental group=10	8 to 14	Functional balance	BESS test	Results showed significant improvements in the balance of the experimental group after an eight-week training protocol.
Sajjadi Manizani [30]	5	The effect of four weeks of treadmill training on static and dynamic balance of the blind and visually impaired	Control group=13 Experimental group=13	11.16±1.69	Static balance and dynamic balance	Static balance=stork test Dynamic balance=Y test	Training with a treadmill on a smooth and sloping surface improves static and dynamic balance in visually-impaired people.
Mavrouniotis et al. [31]	4	The effect of a combined training program with Greek dances and Pilates on the balance of blind children	Control group=5 Experimental group=9	Control group=16.40±1.34 Experimental group=15.67±1.32	Functional balance	1. Set of motion assessment-tests 2. Bruininks-Oseretsky Test	An eight-week training protocol of pilates and Greek dance has positive effects on the balance of blind children.
Morelli et al. [32]	6	An exergame to improve balance in children who are blind	Control group=0 Experimental group=11	9 to 16	Postural sway	Balance board	Balance in the blind is significantly affected.
Salari et al. [33]	5	The effect of core stability training program on balance in blind female athletes	Control group=15 Experimental group=15	22.40±5.35	Static balance and dynamic balance	Static balance=Single-limb stand Dynamic balance=Y test	Core stability exercises significantly improves static and dynamic balance in blind women.
Eshaghi [34]	4	The effect of yoga exercises on balance and head forward complication in blind male students	Control group=8 Experimental group=8	15.75±1.58	Postural sway	Biodex Stability System	Yoga exercises improve balance and treat forward head posture.
Wiszmirska et al. [35]	7	The impact of a vestibular-stimulating exercise regime on postural stability in people with visual impairment	Group without visual impairment=42 Group with visual impairment=28	Group without visual impairment=18 to 20 Group with visual impairment=The average age is 19 years	Balance assessment in different sensory conditions	Biodex Stability System	Exercises that involve the vestibular system with head and body movements are helpful for visually-impaired people.
Khorami Moghadam [36]	5	The effect of water exercise on the balance and coordination of blind boys	Control group=10 Experimental group=10	9 to 15	Static balance, dynamic balance, and gait coordination	Static balance=stork test Dynamic equilibrium=Y test Coordination=Tandem gait	Training programs in water have significant impacts on balance and coordination in male blind subjects.
Hosseini et al. [37]	5	The effect of two water and physical training protocols on balance in blind male students	Control group=12 Water exercise group=12 Exercise group with physio-ball=12	7 to 12 years	Postural sway	Platform	Both gym ball exercises and in-water exercises improve balance indexes in the blind. The results also showed that the balance indexes in the exercise group with physio-ball were higher than the exercise group in water.
Eskandari [38]	6	The effect of balance exercises on the patterned surface on the balance and coordination of the blind	Control group=10 Experimental group=10	26.13±5.2	Static balance and dynamic balance	Static balance=stork test Dynamic balance=Y test	Training protocols on patterned surfaces improve balance in the blind.

Authors	PEDro Scale	Article Title	Sample Size	Age (y) Range	Measured Variables	Instrument	Main Results
Moffa et al. [39]	5	Acute effect of whole-body vibration on balance in blind vs no-blind athletes: a preliminary study	Control group=10 Experimental group=11	Control group=31.5±1.7 Experimental group=29.2±2.3	Static balance	Platform	Acute vibration has no effects on balance in blind or normal people.
Sadeghi et al. [40]	5	Effectiveness of Core Stabilization Exercises on Balance and Gait speed of blind students	Control group=14 Experimental group=14	Control group=11.46±0.91 Experimental group=10.8±0.94	Static balance Dynamic balance gait speed	Static balance=foot scan Dynamic balance=TUG Test gait speed=8 meters walking	Core stability exercises have significant effects on the dynamic balance and gait speed of the blind.
Yousefian et al. [41]	4	Effect of Initial Orientation and mobility training, and advanced	Control group=40 Experimental group=40	5 to 14	Functional skills and functional balance	Bruininks-Oseretsky Test	A 12-week training protocol of movement skills has significant impacts on functional performance and balance in the blind.
Rajabi et al. [42]	5	The comparison effects of eight weeks of spark and Frenkel exercises on static and dynamic balance in the blinds	Control group=10 Frank group=10 Spark group=10	Control group=34 Frank group=33 Spark group=32	Static balance and dynamic balance	Static balance=stork test Dynamic balance=Y test	Frank and spark exercise significantly affect balance in the blind. Also, Frank's exercises had a better effect than spark's exercises.
Mahrokh, Moghadam et al. [43]	6	The Effect of Core Stability Training on Motor Performance of Elite Goalball Players	Control group=13 Experimental group=13	25 to 45	Static balance, dynamic balance, lower limb function, upper limb power, and motor function	Static balance=stork test Dynamic balance=Y test	An 8-week training protocol on core stability has significant effects on the motor performance of elite goalball players
Sioud et al. [44]	7	Auditory cues behind congenitally blind subjects improve their balance control in bipedal upright posture	Group without visual impairment=11 Group with visual impairment=11	Group without visual impairment=29.2±1.2 Group with visual impairment=23.3±1.4	Postural sway	Force Plate	Awareness of sounds from behind increases balance in the blind

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grams to promote balance in visually impaired subjects. Nevertheless, the age and degree of visual impairment need to be taken into consideration in analyses [22].

Melzer et al. studied the effects of auditory-memory attention as a cognitive task on postural control in the blind. They reported that the blind and sighted subjects had similar postural sway in closed eyes condition. Compared with the single task, in the dual-task, the sighted subjects showed a significant decrease in postural sway, while blind subjects did not. The auditory-memory attention-demanding cognitive task does not interfere with balance control in blind subjects [23]. Ozdemir et al. studied the effects of ankle proprioception on the balance of blind and sighted people. They measured the

proprioception and muscular strength of latissimus dorsi, the plantar flexion of the ankle, and postural control with open and closed eyes. Results showed that the blind had better proprioception in closed eye condition, and normal people had higher balance in open eye condition. The two groups did not significantly differ in terms of postural control. The authors concluded that ankle proprioception could not make up for poor balance in the blind [24].

Schmid et al. explored visual information as an alternative to other sensory data in static and dynamic balance. They studied 25 congenital and acquired blind subjects and compared them with normal people. Results showed that normal people experienced the same postural control as the blind, in closed eye condition, also, they had higher

postural control in head and hip segments. On the other hand, the blind experienced higher postural control in head and hip segments, in dynamic balance. Congenital and acquired blind subjects showed similar behavior in both static and dynamic balance. The authors concluded that blindness could not be compensated for by other sensory data. This is in contrast with cross-modal plasticity in blind people and confirms the assumption that vision plays a significant role in processing and integrating other sensory information [25]. Shusharty et al. studied the frequency and latency of vestibular evoked muscular potentials, in normal and congenital blinds and found no significant differences between them. The authors reported that the formation of the neural pathway and the reflex arc of vestibular evoked muscular potentials were the same in both groups and independent of the visual system [26]. Farsi et al. manipulated sensory systems in the static balance of blind and sighted people. They stated that sway increased in both groups during static balance, but the manipulations of the vestibular system did not affect blind people and they showed no decreased balance. Also, the highest impact was observed in somatosensory manipulations. Thus, it seems that blind and sighted people use different mechanisms to apply sensory data to maintain balance [27]. Mohammadi et al. studied the performance of the somatosensory system in the postural control of blind athletes and nonathletes. They found that in cases of dominant somatosensory information, blind goalball players had better performance than other nonathlete blinds and even nonathlete sighted people. Thus, goalball and its related features positively promote the somatosensory system [28].

4. Discussion

The present study evaluated balance in the blind. It aimed to 1) evaluate the balance adaptation in the blind and 2) identify the effects of training protocols on balance in the blind.

Balance Adaptation in the Blind

Comparing balance in the blind and sighted subjects

Maintaining posture and balance is a function of the mutual processing of sensory input from different sensory systems, such as visual, vestibular, and proprioception systems. If any of these systems fails to work properly, balance is impaired [45]. Studies assert that vision also plays a key role in maintaining balance and posture and is more influential than other sensory systems [46]. Therefore, blind people are deprived of the most useful sensory system that provides the most essential information from

the environment. Visual disorder leads to poor balance and postural control [47]. It is asserted by Aydog et al. Tomomitsu et al. Barati et al. Rutkowska et al. and Muursepp et al. that postural control is weaker in the blind than in their healthy counterparts [16-18, 21, 22]. It is also found that blind people rely on hip strategy to maintain balance [9, 11]. Besides, congenital versus acquired blindness is studied in the literature. Nakata et al. stated that congenital balance has little or no effect on controlling postural sway [12]. Schmid et al. reported that congenital and acquired blindness similarly affect static and dynamic balance [25]. However, this needs further and more elaborate studies. The literature also includes studies on the intensity of visual impairment. Intensive visual impairment negatively affects balance maintenance [22].

Häkkinen et al. observed no difference between blind and sighted subjects in the muscle mass volume, maximum muscular strength, and vertical jump [19]. Giagazoglou et al. studied the isometric power of the ankle and hip muscles in blind and sighted subjects and found no significant difference [15]. Horvat et al. compared isokinetic peak force and strength in visually impaired and blind adults and reported no significant difference [13]. Moreover, Ray et al. realized that the major components of strength and balance are low in people with visual disorder [9]. Nakata et al. reported that the electromyography activity of gastrocnemius muscle in the blind was lower than in their healthy counterparts [12]. There are contrasting results on the strength of the lower trunk in the blind, also, weakness in the lower limbs may explain poor balance in these people. Mohammadi et al. showed that when somatosensory input is dominant, postural control in blind goalball players is better than in nonathlete blinds and even sighted athletes [28]. This also needs to be carefully studied.

Rutkowska et al. studied balance in the blind and found that gender played no role in balance maintenance [20]. This was inconsistent with the findings of Horvat et al. [13]. Also, Smith et al. studied the effects of gender on postural control in children aged 8 to 12 years and found that girls had better control than boys [48]. Similarly, Mickle reported that boys experienced more postural sway than girls; this was exacerbated by more difficult situations [49]. Nevertheless, boys show greater muscular strength in the lower limbs, which is essential to the balance of muscular strength. Besides, boys have higher mobility than girls. The effects of gender on balance in the blind needs to be further studied.

Effects of age on balance

Häkkinen et al. examined the effects of age on balance in the blind before and after puberty and reported that the blind had weaker balance before puberty (9-13 years of age) than after puberty (15-18 years of age) [19]. A study on blind subjects aged 7 to 16 years revealed no difference between the age groups of 7 to 11 years and 12 to 16 years [20]. This conflicted with the earlier study that showed poorer balance in the age group of 7 to 11 years than in 12 to 16 years [22]. This is associated with the growth of sensory systems. In this regard, physiological findings indicate that visual, vestibular, and proprioception systems anatomically mature before children reach adulthood [50]. Thus, the somatosensory system grows fully before the age of 3 to 4 years [51] and reaches maturity before the age of 6 [52]. The visual growth of diplopia occurs before 4 to 5 months of age and three-dimensional sharpness matures at 6 to 7 months [53], similar to that of adults. However, another study found that children could not use proprioception for postural control before the age of 12 years [54]. At 15 to 16 years of age, sensory systems for postural control are similar to adults and adolescents [51]. Therefore, sensory systems grow by age, and the poor balance of the blind before adulthood is explained by the fact that other sensory systems (vestibular and proprioception) grow by age and have stronger roles in postural control.

Compensation of balance impairment by other sensory systems in the absence of vision

Schmid et al. showed that sighted subjects had the same postural control as the blind, in closed eye conditions [25]. Also, manipulating the vestibular system, Farsi et al. found no decreased balance and reported the highest impact for somatosensory manipulations [27]. In the case of dominant somatosensory information, blind goalball players had a better performance than other non-athlete blinds and even nonathlete sighted people [28]. Häkkinen et al. showed that sighted and blind people did not differ in balance when vision was excluded [19]. Ozdemir et al. found that ankle proprioception partially compensated imbalance in the blind [24]. Muurespp et al. reported no significant difference between the blind and sighted subjects for balance in closed eye conditions [18]. Finally, Shumway-Cook and Woollacot stated that the maintenance of postural stability is a function of integrated sensory data from visual, vestibular, and proprioception systems. Any lapse in one system is made up for by the other two [55]. Studies show that vestibular and proprioception systems are adopted in the absence of visual input. Thus, sighted and blind subjects have the

same performance in such cases. However, to our surprise, only the results of Mohammadi et al. showed that proprioception was stronger in the blind than in sighted people [28]. Schmid argued that cross-modal plasticity was a controversial issue in the blind and asserted that vision plays an important role in processing and integrating other sensory inputs as well as selecting appropriate strategies for postural control [25]. Shusstary et al. showed that the neural pathway and reflex arc of vestibular evoked muscular potentials are formed similarly in both blind and sighted subjects and are independent of the visual system [26]. More studies are needed to figure out the contribution of vestibular and proprioception systems in the blind and sighted population.

Effects of training protocols on balance in the blind

Studies show that training and rehabilitation protocols decrease imbalance and can be used as a strong inter-ventive treatment for children with visual disorder and balance dysfunction. The review of the literature showed that all training, rehabilitation, and exercise programs positively affected the balance improvement in the blind [29-44]. Mobility is one key element in these protocols because a sedentary lifestyle explains a certain aspect of imbalance in the blind population. Nevertheless, this conclusion should be made with caution, because the studies show poor quality. It is not well-documented in the literature which training protocols have the greatest effects on balance in the blind, as they ignore effect size in measuring the impacts of training and rehabilitation programs. Moreover, the reliability of tests was not validated. For postural control, the blind relied on hip rather than ankle strategy [9, 11]. It is not clear whether measuring tests were appropriate for examining balance in them. It seems that training protocols that strengthen other sensory systems (vestibular and proprioception) are more appropriate because the blind rely on proprioception more, compared with sighted people [11, 27, 28].

This paper performed a systematic review of existing literature but provided no qualitative analysis. Although all the articles were retrieved from authentic databases, the results of our analysis were generalized with caution. Besides, only articles in English and Persian were considered for study. Therefore, future studies are suggested to focus on offering qualitative analysis.

Our comprehensive review of the literature showed poor balance in the blind, though they showed similar performance as that of the sighted subjects, considering the vestibular and proprioception inputs. Also, balance

in the blind improved by age, because vestibular and proprioception systems develop by age. However, the literature does not cover the effects of these systems on balance maintenance. Results also revealed that the blind mostly rely on hip strategy. On the other hand, all training protocols and exercises were found to have positive effects on balance in the blind, though there was no subtle analysis on the most influential protocols. As the blind population mostly relies on vestibular and proprioception input, it seems wise to focus on programs that enhance these sensory systems to improve balance in the blind.

Ethical Considerations

Compliance with ethical guidelines

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All authors equally contributed to preparing this article.

Conflict of interest

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